Electron Polarimetry Update: Considerations of detector location, granularity and laser requirements

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EIC Science Task Force Meeting

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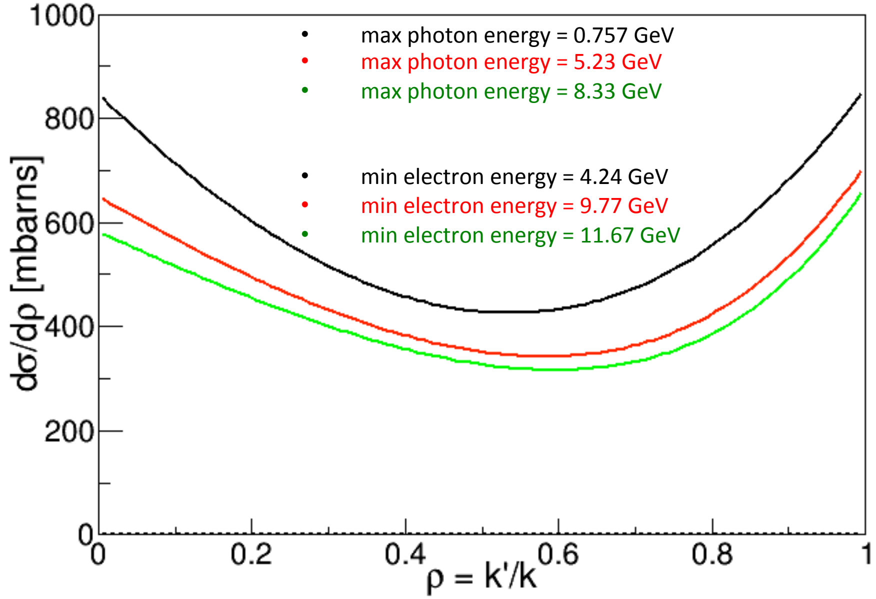
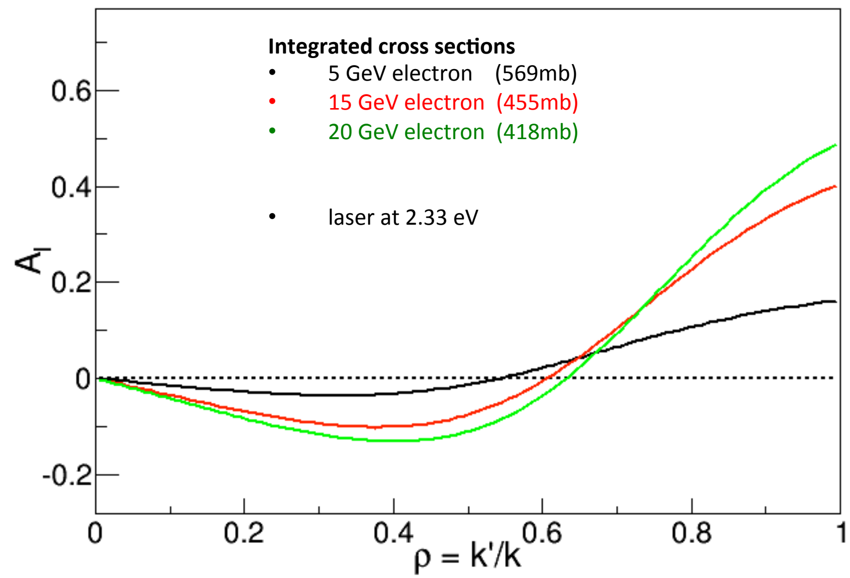
Outline

current goal: determine requirements on detector placement and geometry, as well as laser requirements to make a 1% level or better measurement on e beam polarization

- electron polarimetry basics
- tunnel geometry and magnets
- detector simulations
- extracting the polarization with a fit procedure
- considerations for the laser requirements
- summary and do to list

Electron Polarimetry Basics





- Use the Compton backscattering process for polarization measurement

$$e+\gamma \rightarrow e+\gamma$$

- shine a laser on the electron beam
  - alternate the helicity state of the photons from the laser
- measure the energy asymmetry of scattered electron/photon between the 3/2 and ½ states

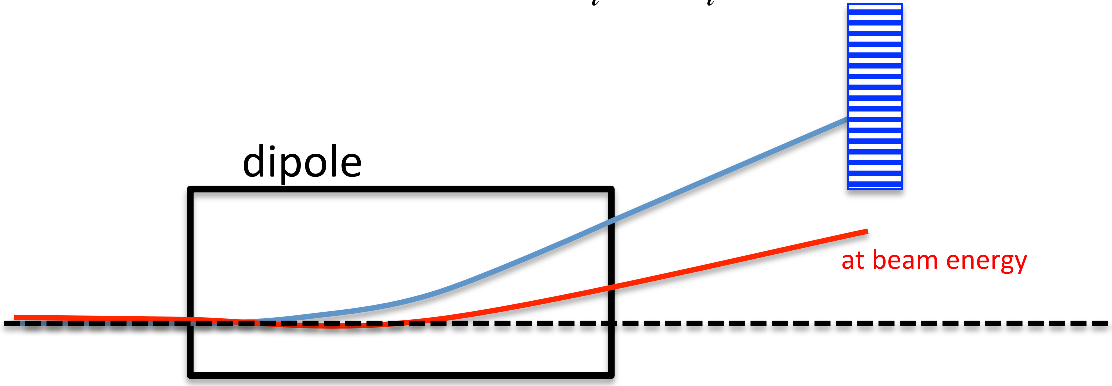
$$A_{\exp} = P_e P_\gamma A_{theory}$$

- The rest of the presentation focuses on measuring the scattered electron

Measuring A_{exp}

- focus on measuring the scattered electron
- measure after some dipole magnet so that the scattered electrons at lower energy separate from the beam
- measure the electron a strip detector
- the strip number that the electron hits is directly related to the energy of that electron
- so we can measure the counting asymmetry in each strip separately

$$A_{\exp,i} = \frac{n_i^+ - n_i^-}{n_i^+ + n_i^-}$$



A_{theory} in Terms of Strip Number

$$\frac{d\sigma_0}{d\rho} = r_0^2 a\left[\frac{\left(\rho(1-a)\right)^2}{1-\rho(1-a)} + 1 + \left(\frac{1-\rho(1+a)}{1-\rho(1-a)}\right)^2\right]$$

$$\frac{d\sigma_1}{d\rho} = r_0^2 a\left[\left(1-\rho(1+a)\right)\left(1-\frac{1}{\left(1-\rho(1-a)\right)^2}\right)\right]$$

$$A_{theory} = -\frac{d\sigma_1/d\rho}{d\sigma_0/d\rho}$$

with:

- $\rho = k'/k'_{max}$, the scattered photon energy relative to the max
- a is a kinematical factor
- $E'_e = E_e + k - k'$ is the scattered electron energy

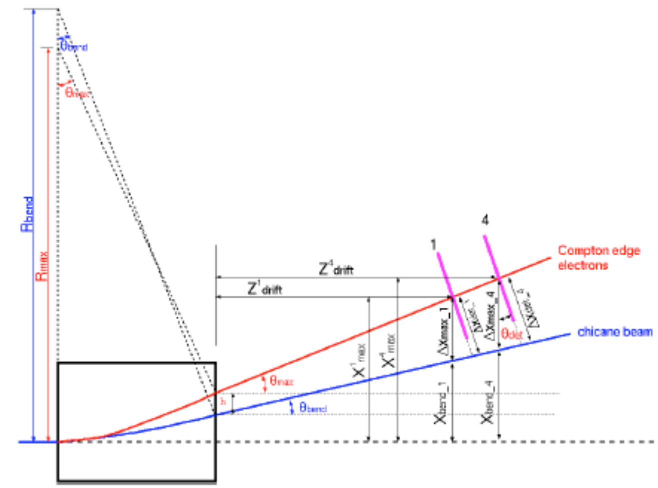
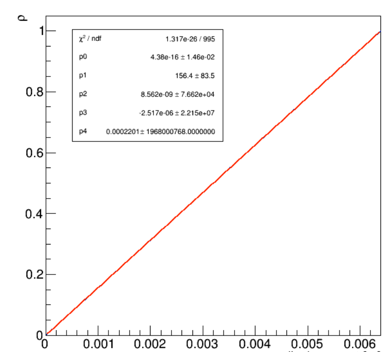


Figure 5.16

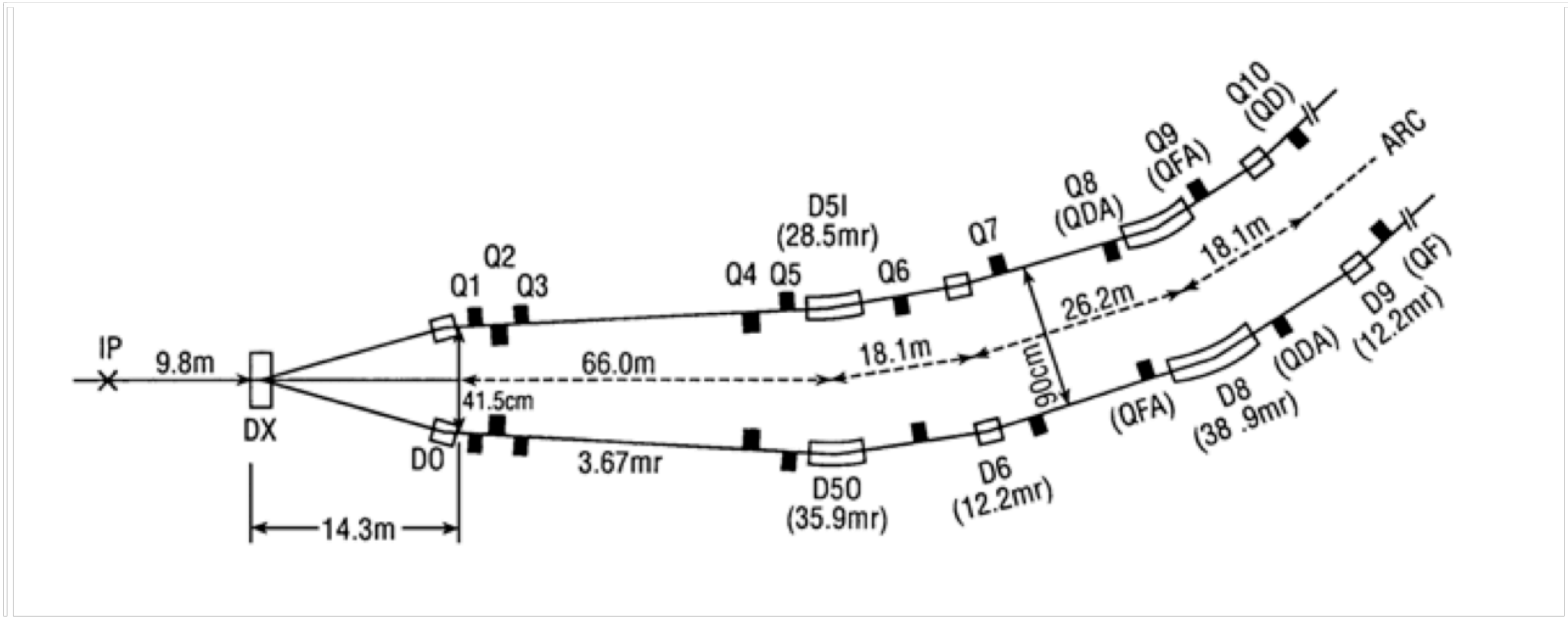
Schematic spatial distribution of Compton scattered electrons

- given details of the setup, one can translate the above equations to be a function of strip number rather than ρ
  - the magnetic field strength
  - the length of the dipole
  - the length of the drift between the dipole and detector
  - the strip width and detector orientation
  - the beam energy and the Compton edge
- this was implemented in code and an analytic relation between ρ and strip number was established (only for one specific implementation, details to follow)
- connecting delta(x) to strip number, n → delta(x) = stripPitch*(n – n_{CE})

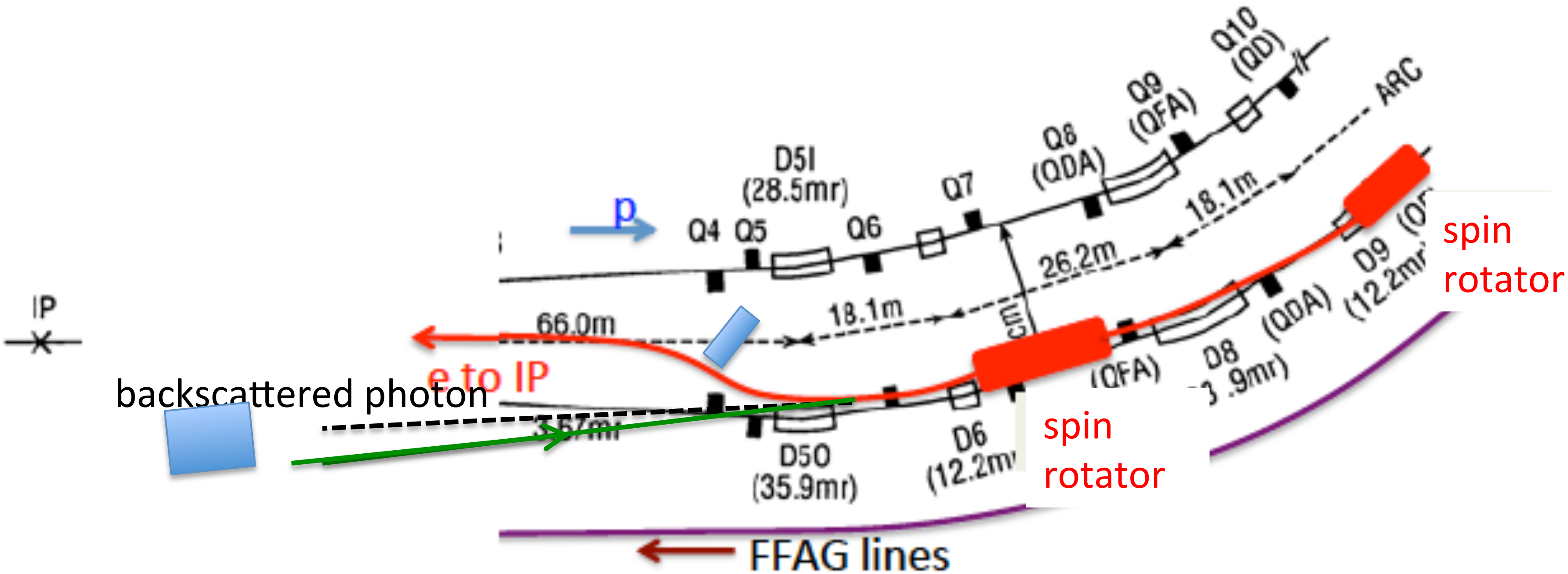


The RHIC Tunnel: Dimensions

- A schematic of the tunnel



Possible Location of Spin Rotators in Tunnel



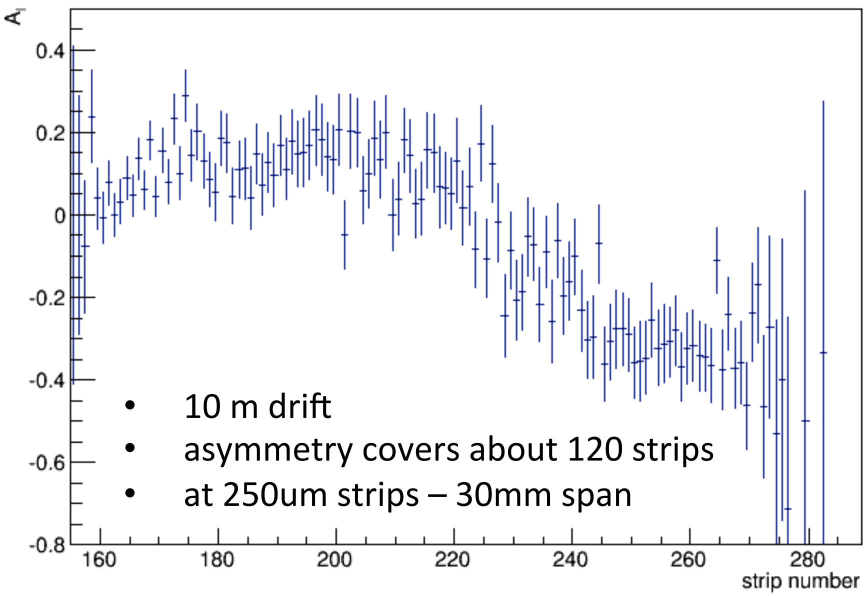
Lattice Design in the RHIC Tunnel

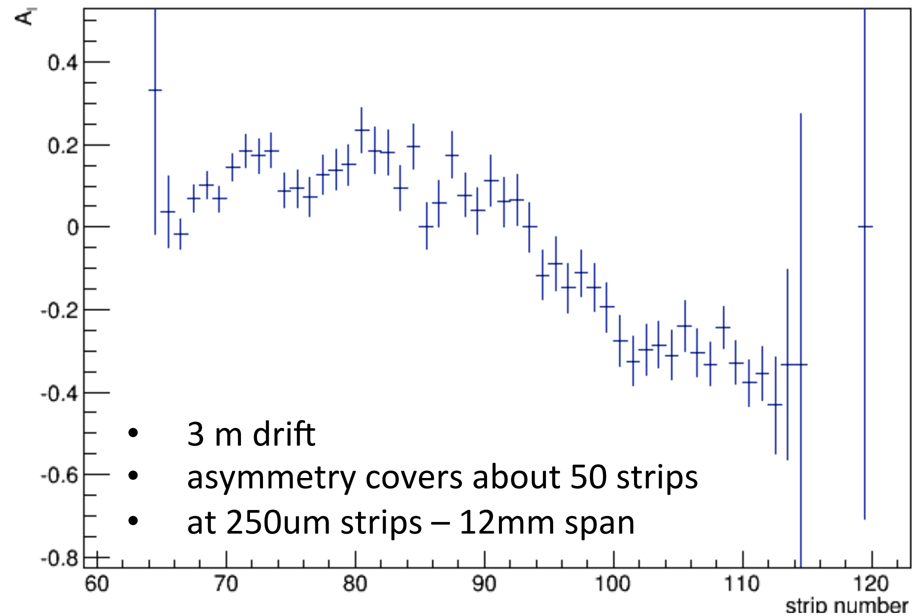
- there is currently no design for the orbit shift that needs to be done for the electron beam going into the IP
- but Vadim gave some guidance so can at least look to some requirements:
  - orbit shift achieved through a series of 2m long dipoles
  - dipole field strengths no more than 0.2T
  - drift distances no smaller than 3m (for possible implementation of quads)
  - the shift needs to be accomplished in 60m from the IP
- Based on this, the following assumptions are made for the study
  - consider placing an electron detector after a single dipole
  - dipole of length 2m with a field of 0.2T
    - for 20GeV e, kick of about 6mrad
    - for 15GeV e, kick of about 8mrad

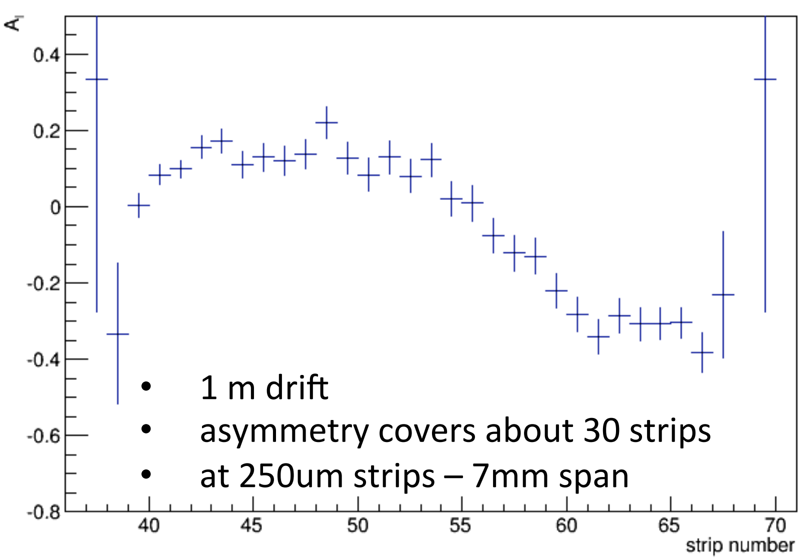
Simulation Setup

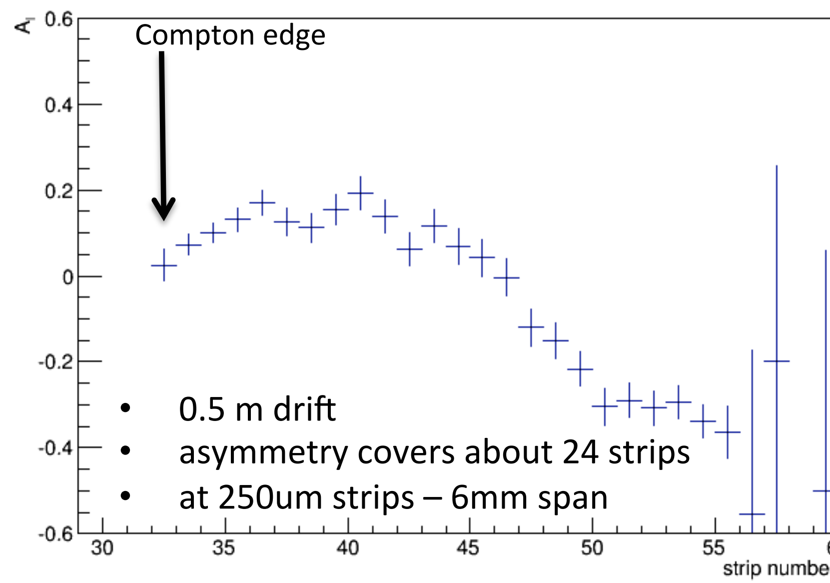
- use simulations to perform an initial exploratory analysis
- Compton events input
  - realistic distributions pulled from QED analytic expressions
  - assume a zero crossing angle of laser and electron beam for now
  - generate 10,000 events for each helicity state combination
  - generate with a polarization of 80%
- magnet placement
  - a single 2m dipole with B=0.2T
- detector simulation
  - use EicRoot
  - implement a very simple single layer sensor
  - digitize the hits into strips of a particular width
    - hacked to simply return the strip number that was hit
  - vary the drift distance to the detector while keeping the strip width constant
  - note that the sensor is currently placed IN BEAM
    - to handle this, polarization extraction does not use the entire A_{exp} distribution

Simulation Results on A_{exp} with varying drift distance







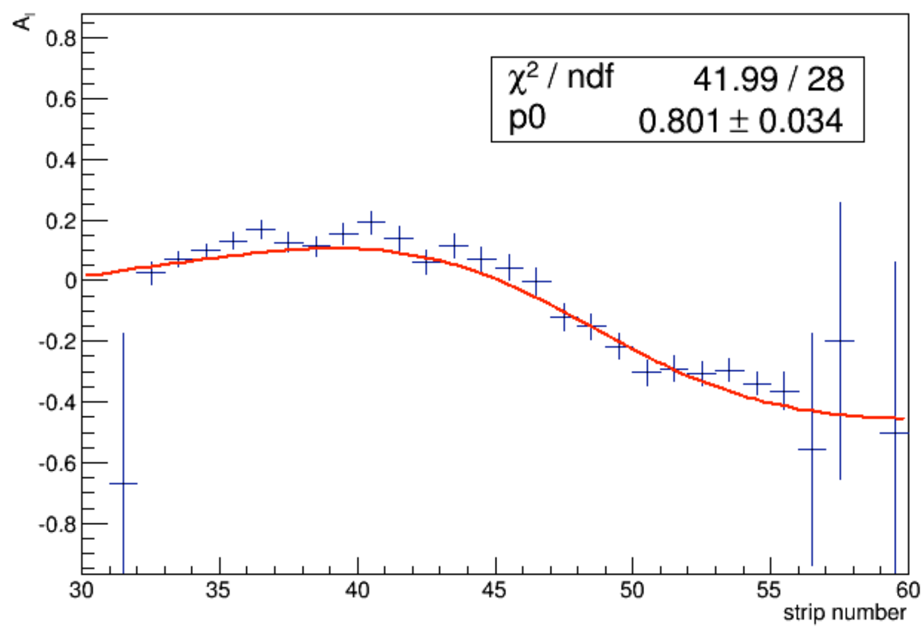


Observations

- from a statistics per strip perspective, a closer sensor is better
- the asymmetry is observed for all cases studied (250um strip pitch, and $0.25 < z < 10$m)
- big question: are the scattered electrons separated enough from the beam?
  - total spread (including Compton edge at beam energy) in the range 5 to 30mm for the cases studied
  - this means we need a small beta function in this region

Extracting the Polarization

- use a fit method
  - fit A_{theory}(strip number) to A_{exp}
  - single fit parameter, P_e
  - assume $P_\gamma = 1$
  - fix the Compton edge strip number
- sort of works, but the strip location of the Compton edge needs to be adjusted for a good fit
  - simulation shows n_{CE} should be 32, but need to set it for 29 for a good fit
    - fixing this, in principle this can also be a fit parameter
  - still looking for the error
- Can use these distributions and procedure to produce a fast MC study to determine the statistics needed for a 1% level measurement
  - push this further to determine laser requirements and time requirements, etc.

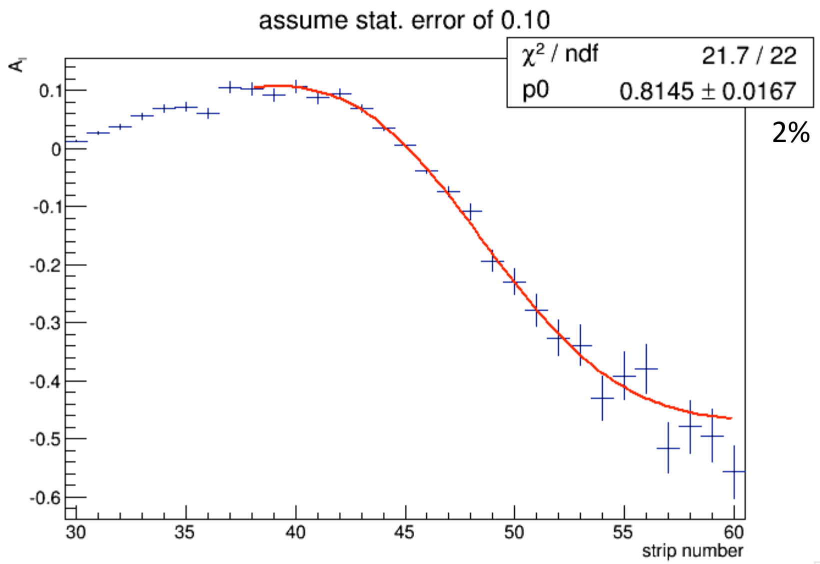


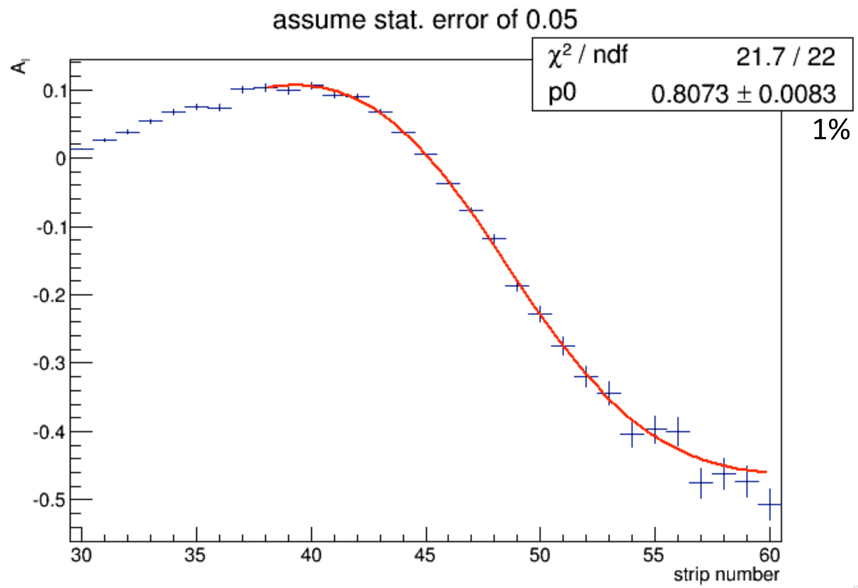
What Rates are Needed for a Good Measurement?

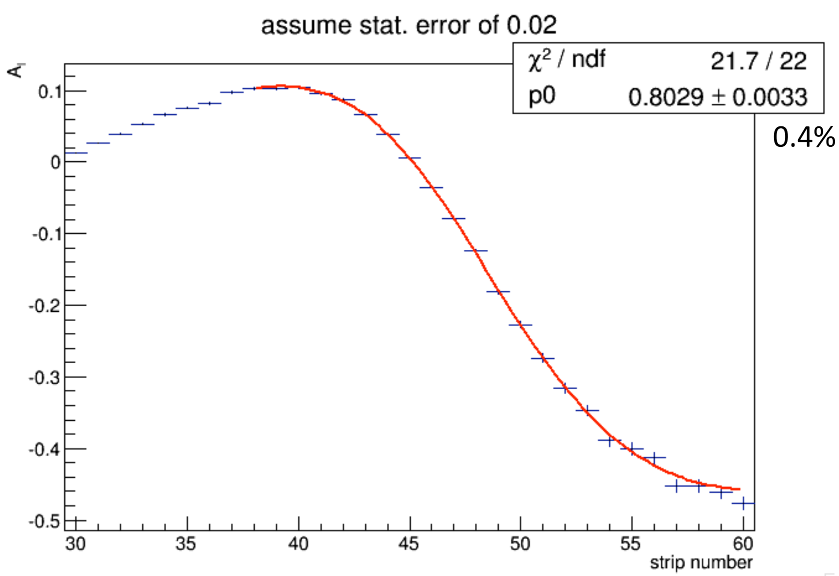
- Need to measure bunch by bunch (and hence cathode by cathode) polarization
- focus on the 0.5m installed detector
- use distribution on previous slide to generate fake data
- generate data with different statistical uncertainties on the points

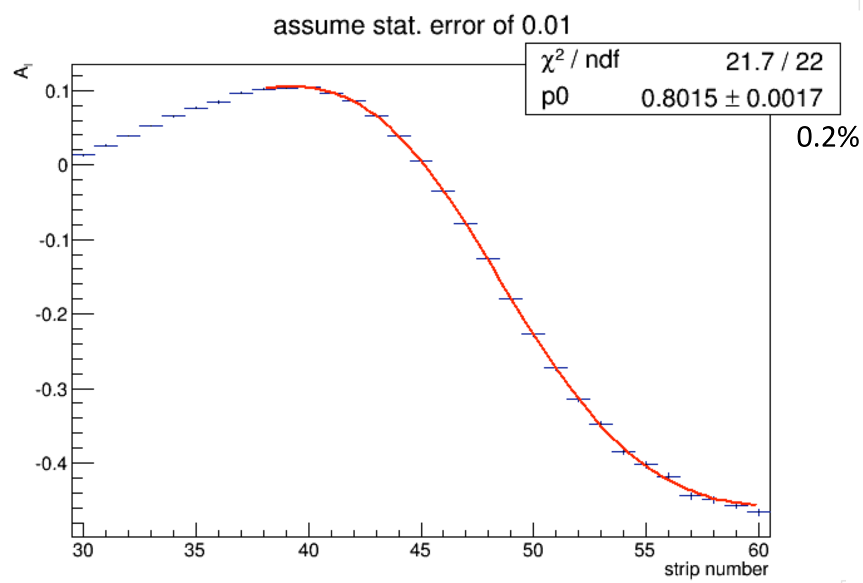
How Stats affects fits…

- need to repeat study with an ensemble of measurements for each error, but an example is shown for now









How Many Events are Necessary for a Particular Statistical Uncertainty on A_{exp}

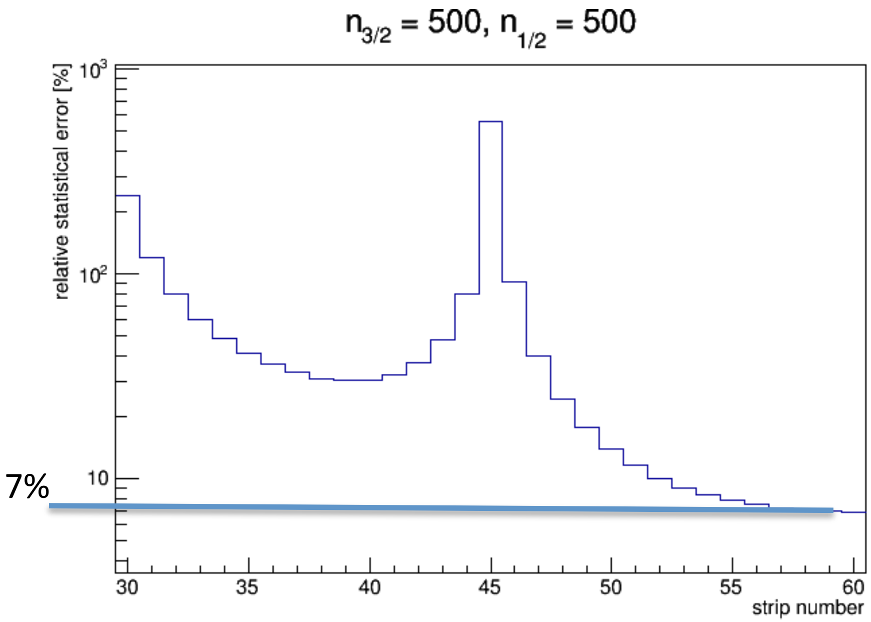
- start with A_{exp} $$A_{\exp,i} = \frac{n_i^+ - n_i^-}{n_i^+ + n_i^-}$$
- propagate the uncertainty through on n to the final asymmetry

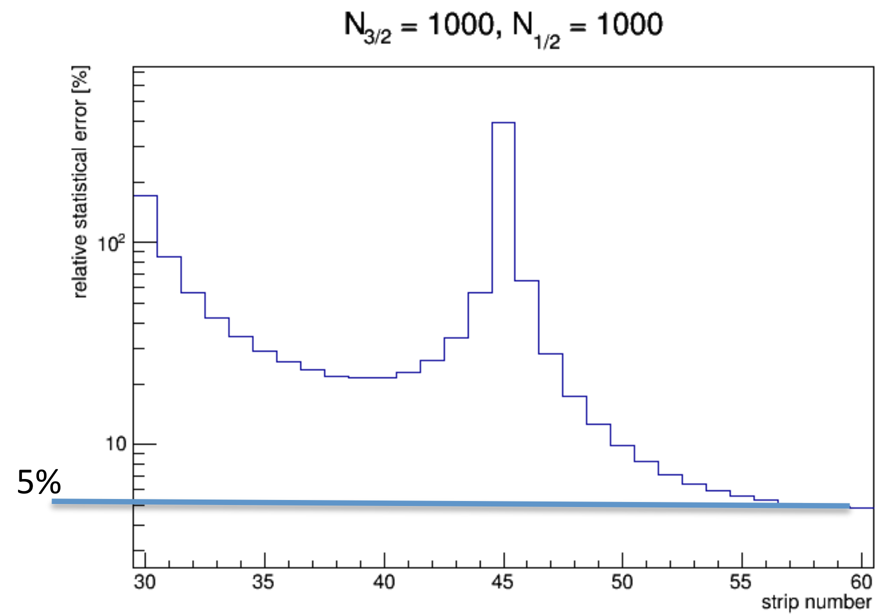
$$\sigma_{A_{\exp}}^2 = \left|\frac{\partial A_{\exp}}{\partial n^+}\right|^2 \sigma_{n^+}^2 + \left|\frac{\partial A_{\exp}}{\partial n^-}\right|^2 \sigma_{n^-}^2 \qquad \sigma_{n^{+/-}} = \sqrt{n^{+/-}}$$

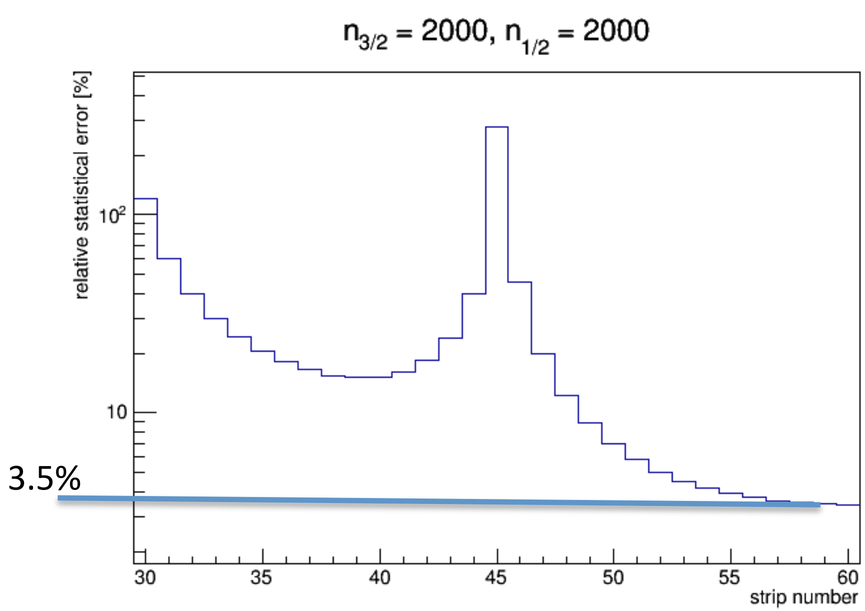
- assuming some number of counts for each strip (assumed flat for now, which is not physically correct), we can calculate the relative statistical uncertainty (given the theoretical asymmetry) on each point

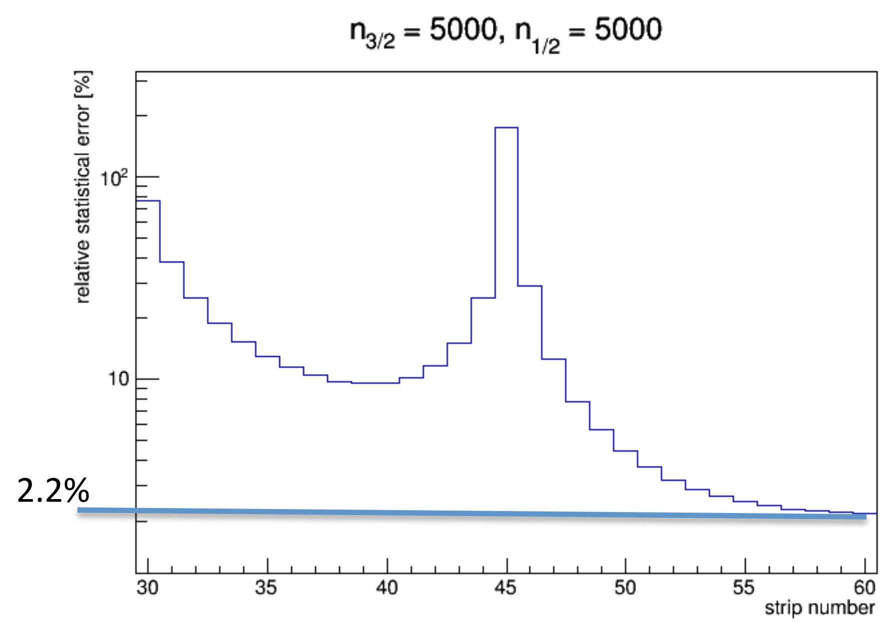
counts/strip	500 counts	1000 counts	2000 counts	5000 counts
uncertainty	0.0316	0.0224	0.0158	0.01000

Relative Uncertainties from a Number of Hits Per Strip









Laser Requirements

What can effect the laser performance?

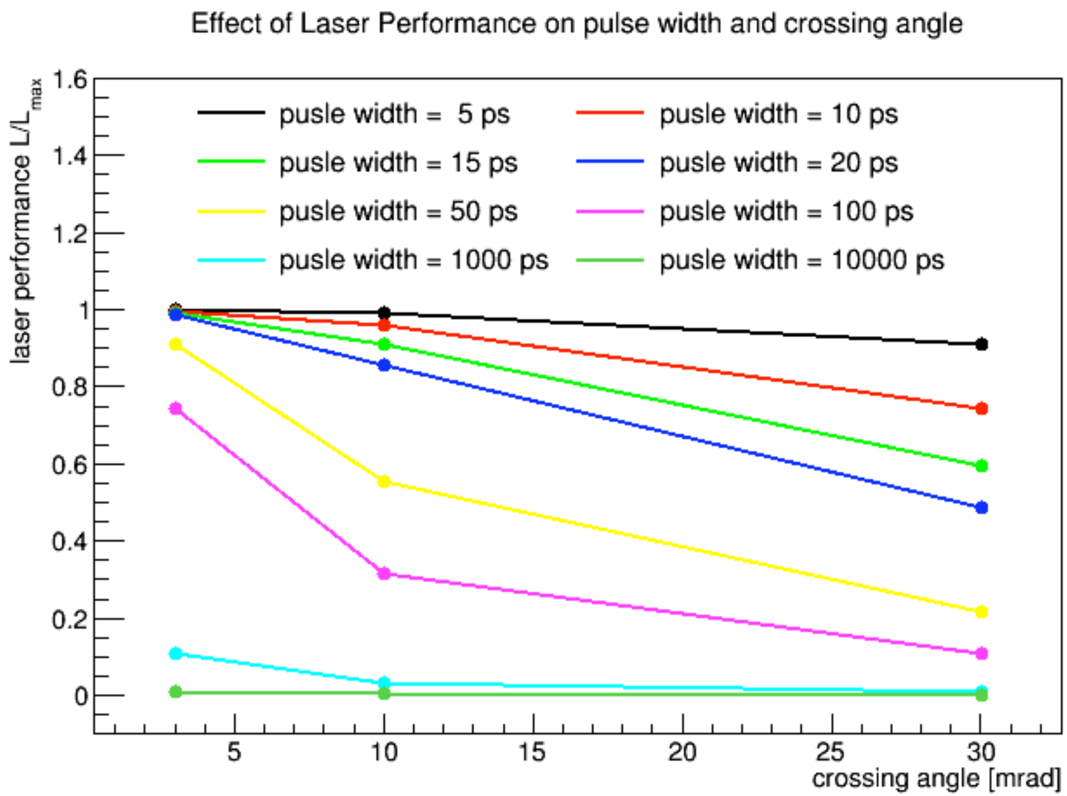
ref: http://www.desy.de/~schuler/LCWS-2007/Upstr_Pol_Update_rev.pdf

- Compton event luminosity can be affected by:
  - laser pulse width
  - crossing angle
- want to minimize crossing angle and pulse width to maximize luminosity

$$L_{\max} = \frac{f_b N_e N_\gamma}{2\pi\sigma_{x\gamma}\sigma_{y\gamma}}$$

$$L = f_b N_e N_\gamma g$$

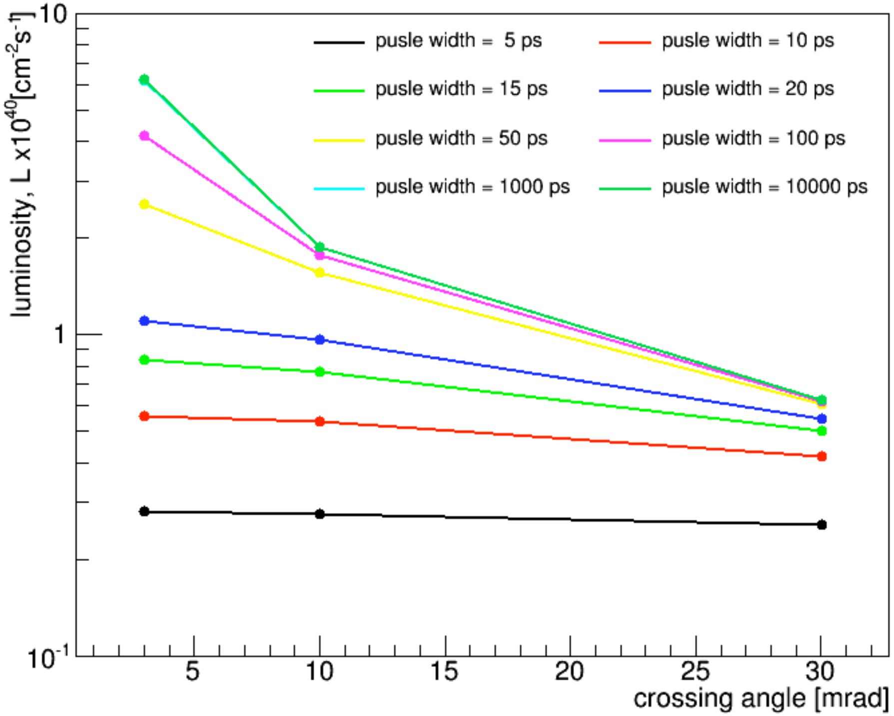
$$g = \frac{1}{2\pi\sigma_{x\gamma}\sigma_{y\gamma}\sqrt{1+\left(0.5\theta_0\sigma_{z\gamma}\sigma_{y\gamma}\right)^2}}$$



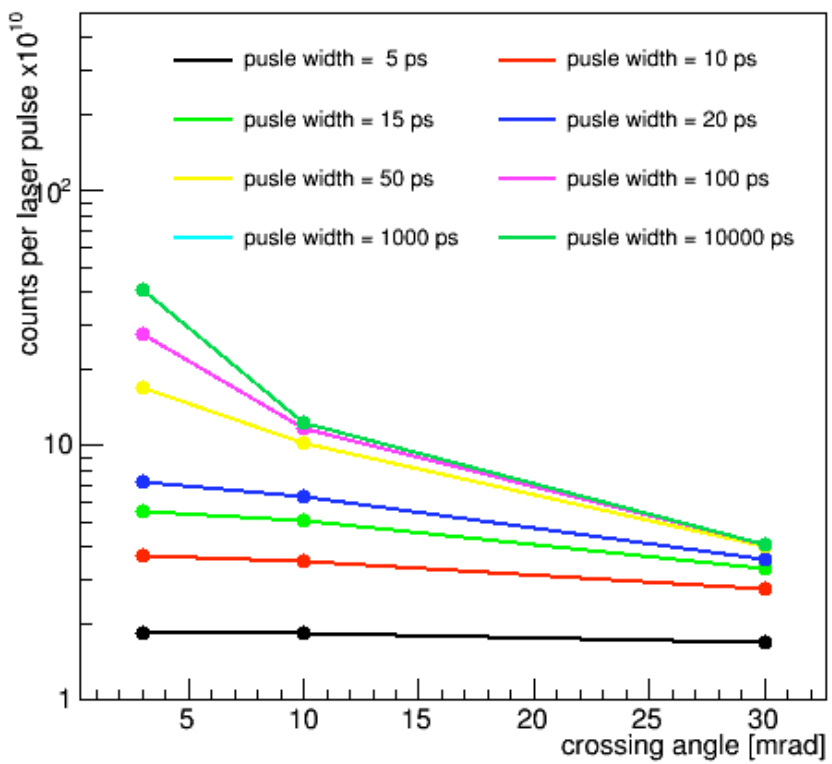
assume:

- 50um transverse width beam
- f_b = 9.4MHz
- N_e = 0.07e11
- laser power = 0.5W
- photon energy = 2.33 eV

The expected luminosity as a function of laser parameters



20GeV x 2.33eV Compton cross section ~418mb



Summary

- electron polarimetry studies are underway
  - have a simple Compton event generator
  - have an NLO MC also (COMRAD), but doesn't seem to be functioning at the moment
  - simple sensor plane implemented
  - simple magnet setup implemented
- studied the drift distance dependence on the polarimetry measurement
  - main concern is how close can we get to the beam or is the spread from the beam large enough
- implemented code to extract the polarization from hits in the detector through a fit procedure
- studied the kind of statistics needed for a 1% level measurement
  - need a stat. error < 5% per strip → ~1000 hits per strip from each helicity state
- started to consider what type of laser we need
  - so far considered a pulsed laser at 2.33eV (green laser) with a power of 0.5W
  - studied the effect of crossing angle and pulse width on the laser performance

To do

- study the effect of implementing a detector after a second bending dipole
- vary the strip pitch and study the effect
- consider other electron beam energies besides 20GeV

Backups

Lasers at polarimeters from other experiments

configuration	E_0 (GeV)	$<I_e>$ (μA)	λ (nm)	ϵ_γ (eV)	$<P_L>$ (W)	j_γ (μJ)	$\mathcal{L}$ $(10^{32} cm^{-2} s^{-1})$
TESLA-500	250	45	532	2.33	0.5	35	1.5
TESLA-800	400	45	1064	1.165	1.0	71	6.0
Giga-Z	45.6	45	266	4.66	0.2	14	0.2

Table 9: Reference parameters for statistical tables.

laser option	l (nm)	P (W)	E_{max} (MeV)	rate (KHz)	<A> (%)	t (1%) (min)
Hall A	1064	1200	23.7	200	0.98	14
UV ArF	193	32	119.8	1.7	5.26	103
UV KrF	248	65	95.4	3.5	4.30	64
Ar-Ion (IC)	514	200	48.1	15.7	1.98	42
DPSS	532	100	46.5	8.1	1.91	87

Compton Scattering Details

Details on rho to strip number mapping